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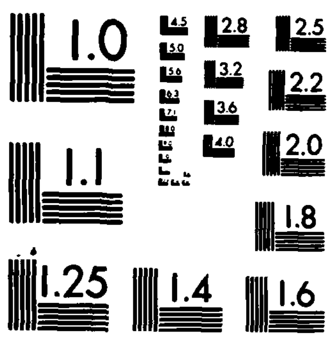

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Risk: The Long and the Short

Amos Tversky
Stanford University

Maya Bar-Hillel
Hebrew University

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Abstract

Normative objections to expected utility theory raised by Lopes (1982) are rebutted and a "fallacy of large numbers", discussed by Samuelson (1963), is analyzed from both mathematical and psychological standpoints.

Risk: The Long and the Short

This paper was stimulated by a recent article of Lola Lopes (1982) "Decision making in the short run", that challenges the normative adequacy of expected utility theory. ~~In the present note we address~~ This note addresses some of the issues raised by Lopes and rebuts her main arguments. ~~We also~~ The note also propose a new normative treatment and a psychological analysis of an interesting gambling problem introduced by Paul Samuelson (1963) in his article "Risk and uncertainty: A fallacy of large numbers."

Lopes argues that, in the short run at least, the probability of winning is a reasonable criterion of choice between gambles. However, the probability of winning cannot serve as a sole criterion since it leads to intransitivity as well as to absurd choices. For example, a sure gain of $1 would be preferred to an even chance to win $5000 or nothing. Lopes acknowledges these difficulties but she does not specify what additional criteria should be considered (the probability of loss? the potential gain? the potential loss?) and how they should be combined. Instead, she discusses three examples involving single and multiple lotteries, intended to support her conclusion that the standard conception of rational choice, based on the maximization of expected utility, "is simply not sensible". We address these examples in turn.

I. Bernoulli's Gamble

The St. Petersburg Lottery (SPL) is a game of chance in which a fair coin is repeatedly tossed until tails first comes up, say on trial n. The player then wins $\$2^n$. This lottery, first introduced by Nicholas Bernoulli and investigated by his younger cousin Daniel, has intrigued many students of probability and decision making who sought to explain the apparent paradox that people are unwilling to pay much for the opportunity of playing a lottery whose expected value is infinite.

Lopes reverses the classical question, and examines the SPL from the point of view of the house, not the player. Imagine, she exhorts us, a fabulously rich individual, called Scrooge, who sells SPLs for $100 apiece. Clearly, in the long run Scrooge is bound to lose all. However, on the basis of a computer simulation, Lopes concluded that in the course of one million transactions, Scrooge has a 90% chance of being in the black, with an expected profit of 56 million dollars. The balance sheet, Lopes argues, more than justifies Scrooge's venture, despite the risk it entails. "Is Scrooge crazy, then" she asks "to sell a product for infinitely less than it is worth?" (p. 378).

What is in question, however, is Scrooge's honesty, not his sanity. The trouble with Scrooge's venture is that he cannot guarantee to fulfill his obligation to his customers. The SPL sets no upper bound on the size of the prize that a player can win, but Scrooge's ability to pay is clearly bounded. If the maximal

prize that Scrooge can pay a given player is $M, *then the payoff must cease to* double and remains constant after the kth toss, where $k=\log_2 M$. Thus, Scrooge is in fact selling an SPL truncated at k+1 steps, whose expected value is k+1 dollars, not infinity. If, for example, Scrooge's upper limit is a generous billion dollars he is actually offering a game whose fair price is less than $31, since 2^{30} exceeds 10^9. When Scrooge's asking price for such an SPL is $100, he is selling a product not for "infinitely less than it is worth", but for considerably more. To make it a fair game Scrooge should be able to pay $\$2^{99}$, which far exceeds the entire wealth in the world. If one is concerned with real-life problems, rather than with mathematical puzzles, one cannot ignore the inevitable truncation of the game and treat it as if its expected value were infinite.

By failing to admit that he is selling a truncated SPL and to specify his upper limit, Scrooge is being less than honest--much like an insurance company that collects premiums for potential damages it could not cover, in the hope that the worst will not happen. The viability of such business practices depends on the gullibility of people and the laws of the land; it does not have much bearing on the adequacy of expected utility theory.

Once we eliminate the deceptive aspect of Scrooge's offer and truncate the infinite tail of the game, what remains of Lopes' argument? Let us assume, for a moment, that Scrooge can actually finance a 55-step SPL. Lopes' simulation shows that Scrooge can expect to make a relatively small amount of money (less than one billionth of his total assets) by selling one million SPL's at $50 apiece--if

he is willing to bear the risk of a catastrophic loss. Two comments regarding this observation may be in order. First, the selling of SPL's below their expected value is compatible with the expected utility principle and a convex utility function for money. Second, very rich people do not seem eager to finance actuarially unfavorable ventures with a potential catastrophic loss. Lopes' example, therefore, does not provide either a hypothetical argument against the maximization of expected utility or a factual argument against the maximization of expected value.

It might be noted that many scholars, from Poisson to contemporary authors, have argued that the limit on the house's ability to pay dissolves much of the paradoxical character of Bernoulli's original problem. As was noted by these authors (see, e.g., Shapley, 1977, and references therein), a truncated SPL does not provide strong evidence against the expected value criterion. It does not seem absurd to pay 31c for a 30-step penny version of the SPL. This game offers a 6.25% chance to come up ahead and some chance of winning more than ten million dollars. Indeed, millions of people routinely purchase lotteries that have a similar structure at prices that exceed their expected value. Ironically, then, the real challenge to expected utility theory and the risk aversion hypothesis is the purchase of lotteries with a long positive tail at unfavorable prices, not the reluctance to purchase such lotteries at favorable prices.

II. Weaver's Objection

In his book "Lady Luck" (1963) Weaver remarks that one may not be willing to pay the expected value in order to play a particular gamble since "the odds are about 4 to 6 that he will receive no prize at all, and just throw away his investment". (Weaver, 1963, p. 155). Lopes interprets this comment as "rejection of the expected utility principle" and a violation of the von Neuman and Morgenstern axioms. Evidently, she infers from Weaver's observation regarding a particular gamble that he advocates the general principle of maximizing the probability of winning, which is inconsistent with expected utility theory. In fact, however, Weaver does not address the expected utility principle in this context, and does not advocate the rule of always selecting the gamble with the highest probability of winning. Hence, his objection to the expected value model does not constitute an argument against expected utility theory.

Lopes also raises the standard objection that arguments based on expectations are applicable in the long run but not in the short run. This objection, however, does not apply to expected utility theory that is derived from axioms of rational choice that pertain to unique choice situations with no reference to repeated plays. Lopes claims that the absence of long run considerations from expected utility theory "is more apparent than real" because "it is questionable whether probability and values ever really combine except in the long run" (p. 381). But modern utility theory, as conceived by von Neumann and Morgenstern, does not assume that value and probability "really combine". It assumes

only that the cash equivalent of a lottery depends on both the value of the prize and the probability of getting it. Expected utility theory does not even assume that receiving the lottery or its cash equivalent have the same impact on subsequent choices, as will be illustrated below.

III. Samuelson's Theorem

Paul Samuelson (1963) tells of a distinguished scholar, unskilled in mathematics, to whom he offered an even chance to win $200 or lose $100 depending on the toss of a coin. Samuelson's Colleague, whom we call SC, declined the single bet but expressed a willingness to play it 100 times. This pattern of preferences has some intuitive appeal, but Samuelson finds it normatively unacceptable, noting that multiple play compounds risk rather than reduces it. Lopes, on the other hand, justifies SC's preferences and regards them as evidence against the normative adequacy of expected utility theory.

According to Lopes, "Samuelson proves the theorem that no one who wants to maximize expected utility--which is a goal his colleague claimed--can agree to a sequence of bets if each of the single bets is unacceptable" (p. 382). If SC's behavior is justifiable, Lopes argues, then expected utility theory must be wrong. As shown below, however, this is not the case. There are many utility functions for wealth that reject the single gamble and accept the multiple gam-

ble. For example, define

$$u(x) = \begin{cases} (x-z)^{\theta} & \text{if } x \geq z \\ -(z-x)^{1/\theta} & \text{if } x \leq z \end{cases}$$

for some $0<\theta<1$. Figure 1 displays the proposed function for $\theta = .93$.

Insert Figure 1 about here

This function is concave everywhere since every cord joining two points on the curve lies below the curve. Hence, it is risk averse and the degree of risk aversion, $r = -u''/u'$, decreases with the distance from z. A person with this utility function will always prefer a sure thing to a gamble with the same expected value. Furthermore, at asset position z, this person will decline the single game (equal chances to win $200 or lose $100), but accept two (or more) plays of the game. To verify note that

$$\frac{1}{2}u(z + 200) + \frac{1}{2}u(z - 100) = \frac{1}{2}(200^{.93}) - \frac{1}{2}(100^{1.075})$$

$$= -1.61<0 = u(z)$$

but

$$\frac{1}{4}u(z+400) + \frac{1}{2}u(z+100) + \frac{1}{4}u(z-200).$$

$$= \frac{1}{4}(400^{.93}) + \frac{1}{2}(100^{.93}) - \frac{1}{4}(200^{1.075})$$

$$= 27.56>0 = u(z)$$

Contrary to claim, then, SC's preferences are consistent with expected utility theory. A careful reading of Samuelson's paper reveals that the proposition he established was that a person should not accept the multiple game *if the*

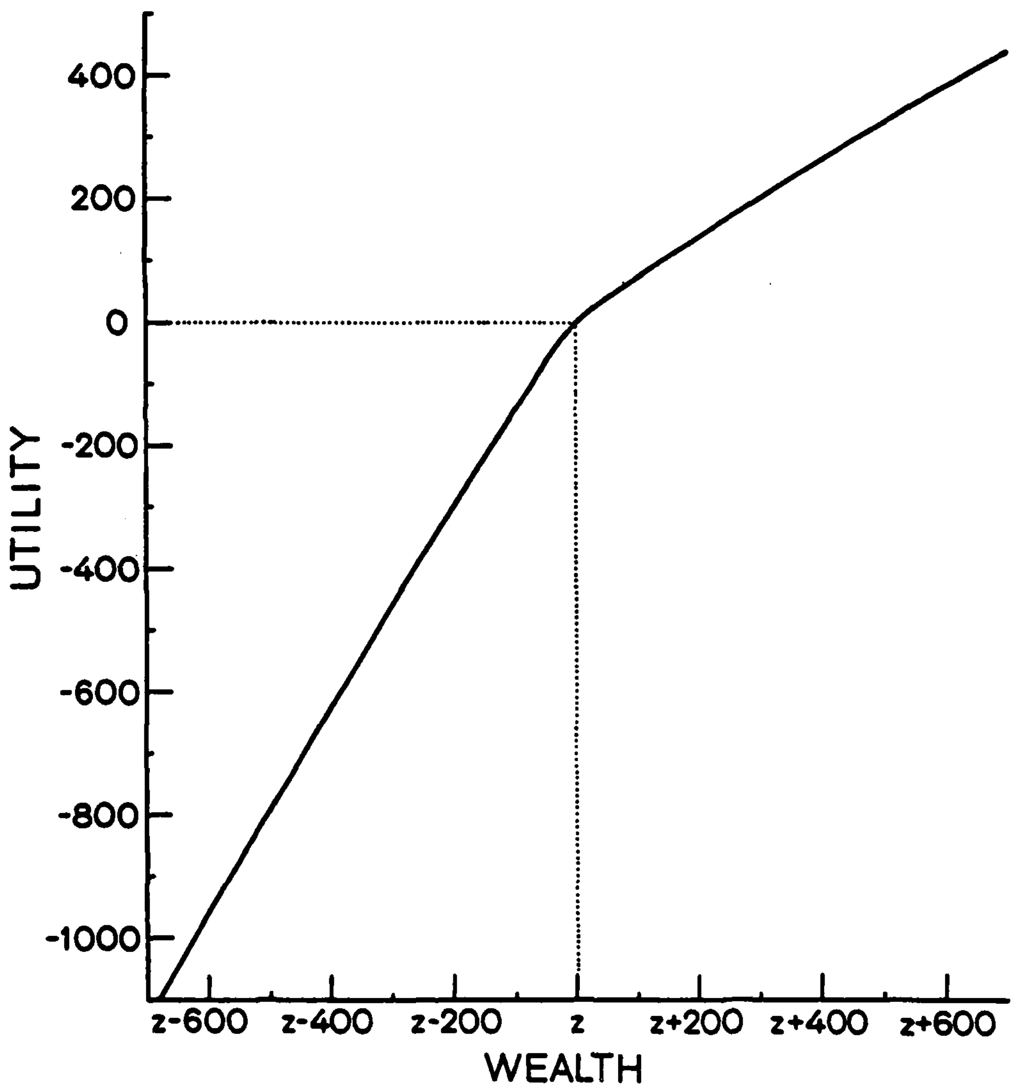

Figure 1. A utility function for SC (θ = .93)

single game is unacceptable at every asset position throughout the relevant range of outcomes. Although Samuelson's discussion of this assumption is informal and brief he specifically cautioned "I should warn against undue extrapolation of my theorem. It does not say one must always refuse a sequence if one refuses a single venture" (1963, p.5). For the entire sequence to be unacceptable, therefore, it is not sufficient that each gamble in the sequence is unacceptable at one's *present wealth;* each gamble must also be unacceptable at *any* possible level of wealth that can be achieved by playing the multiple game. The utility function of Figure 1, for example, satisfies the former but not the latter assumption.

The latter assumption is, indeed, the heart of the matter. If it holds, Samuelson's conclusion follows from transitivity and dominance, without assuming expected utility theory, as will be shown below. In the next section, however, we present illustrative data that cast serious doubt on the descriptive adequacy of the above assumption.

The present discussion is confined to gambles or prospects with monetary outcomes, represented by discrete random variables. As in the standard analysis, we assume that an individual has a transitive preference, denoted $\succ$, between any pair of (final) asset positions. Thus, gamble X is chosen over Y by a person with wealth w whenever $w+X \succ w+Y$. We use lower-case letters, w,x,y,z, to denote monetary values (i.e., constants) and upper case letters to denote gambles (i.e., random variables). In particular, y is said to be an outcome of Y if there is a positive probability that the gamble Y results in the monetary outcome y. We

assume that the preference order between asset positions depends only on their distributions, hence, one is indifferent between asset positions that have the same (marginal) distribution.

Consider a set of gambles played by tossing n coins and having the player receive $200 for each heads and pay $100 for each tails. Let X_k be the gamble on the k-th coin, $1 \leq k \leq n$, and let $S_k = X_1 + \cdots + X_k$ denote the multiple gamble that consists of tossing coins 1 through k. In particular, $S_1 = X_1$ and $S_{k+1} = S_k + X_{k+1}$. Note that a multiple gamble is represented as a sum of random variables.

Since SC rejects a single toss we assume

(1) $w \succ w + X_1$.

Furthermore, the single toss is unacceptable at any level of wealth that can be achieved by 100 tosses, hence we stipulate, with Samuelson,

(2) $w + y \succ w + y + X_1$ for $-10{,}000 \leq y \leq 20{,}000$.

We also assume the following dominance condition

(3) If X and Y are independent and if for every outcome y of Y, $w + y \succ w + y + X$ then $w + Y \succ w + Y + X$.

This condition says that if X is unacceptable at any level of wealth $w + y$ that might result from playing the gamble Y, then X is also unacceptable at $w + Y$ where one does not know for sure which of these levels of wealth will obtain.

Assumption (3) seems unobjectionable on normative grounds and it is weaker than expected utility theory. However, in conjunction with (2), it implies that for every $1 \leq k \leq 100$, S_k must be chosen over S_{k+1}. To prove this proposition note that for any outcome s of S_k, $w+s \succ w+s+X_{k+1}$, by (2) and the fact that X_1 and X_{k+1} have the same distribution. Hence, by (3),

$$w+S_k \succ w+S_k+X_{k+1} = w+S_{k+1}.$$

and by transitivity

$$w \succ w+S_1 \succ \cdots \succ w+S_{100}.$$

Given (2) and (3), therefore, the rejection of S_1 implies the rejection of S_{100}. Our proof is similar, but not identical, to Samuelson's informal argument. Unlike Samuelson's proof, however, the present result does not rely on expected utility theory. It strengthens Samuelson's case against his colleague, by showing that if (2) holds then SC's choices must violate transitivity or dominance. For Lopes, who defends SC, the situation is more difficult: if she endorses (2), she has to defend the violation of transitivity or dominance; if she does not endorse (2) her argument against expected utility theory is invalid.

We do not wish to argue that expected utility theory is the only adequate normative framework for decision under risk; there are many prescriptive aspects of value and belief that are not readily captured in this framework. We merely argue that Scrooge's enterprise, Weaver's objection and SC's preferences do not

cast serious doubt on the normative adequacy of expected utility theory.

IV. Psychological Analysis

Let us turn now from normative theory to psychological analysis. To begin with, it is hardly surprising that the 100 fold gamble S_{100} is attractive: it offers a good possibility for a significant gain while the chances of a loss are less than 1%. It is also not surprising that S_{100} is preferred to the single gamble S_1; the former appears less risky than the latter in the sense that S_{100} has a mean of \$5000 and a standard deviation of \$1500 while S_1 has a mean of \$50 and a standard deviation of \$150. What puzzled Samuelson and others is the rejection of S_1 despite its favorable expectation by people, like SC, who can surely afford a loss of \$100. Evidently, the anticipated psychological impact of the loss offsets the impact of the equiprobable larger gain.

Following prospect theory (Kahneman & Tversky, 1979) and the analysis of framing (Tversky & Kahneman, 1981) we propose that this phenomenon of loss aversion is induced by framing the choice so that the status quo serves as a reference point and the outcomes are evaluated as a gain of 200 and a loss of 100, not as asset positions of $w+200$ and $w-100$. Indeed, if the reference point is changed by framing the outcomes in terms of asset positions (as recommended by decision analysts) or by adding a (positive or negative) constant to all outcomes, the extreme aversion to risk is reduced or eliminated. To illustrate this effect and demonstrate its relevance to our problem, we presented 230 Stanford under-

graduates with a brief questionnaire that included the following problems.

A. Suppose you are offered the following option. Would you accept the gamble?

50% chance to win \$200 and 50% chance to lose \$100.

B. Suppose you are offered the following choice. Which option do you prefer?

– A sure gain of \$600

– 50% chance to win \$800 and 50% chance to win \$500.

C. Suppose you are forced to choose between the following options. Which do you prefer?

– A sure loss of \$200.

– 50% chance to lose \$300 and 50% chance to lose nothing.

Before discussing the data, note that Problems B and C are obtained from Problem A by adding \$600 to all outcomes or subtracting \$200 from all outcomes, respectively. Since a gain of \$600 or a loss of \$200 might occur in the course of playing the multiple gamble, assumption (2) says that a person who rejects the gamble in Problem A must also reject the gamble in Problems B and C. Prospect theory, on the other hand, implies that the tendency to select the gamble will be weak in A, intermediate in B and strong in C. The results support this prediction: 70% of the respondents rejected the gamble in A and among these subjects, 60% accepted the gamble in B and 95% accepted the gamble in C. Thus, the majority of subjects rejected S_1 at their current asset

position but most subjects accepted it when combined with a gain of $600 or with a loss of $200.

The above data indicate that many individuals, who surely vary in asset positions, reject the gamble in A but accept it in B and C. These observations violate assumption (2) and thereby undermine the application of Samuelson's theorem to the problem under study. It appears that the common rejection of the gamble in A and its almost unanimous acceptance in C represents a stable pattern of choice that is unaffected by small changes (e.g., of $200) in one's total wealth. In contrast, the addition of $200 to all outcomes of the offered prospects had a marked impact on preferences, as demonstrated above. These observations reject a utility function that is based on final asset position (of the type presented in Figure 1) in favor of a theory where the carriers of value are gains and losses defined relative to some reference point. Since the value function tends to be concave for gains and convex for losses, the shift of reference point can produce systematic reversals of preferences (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981). In particular, one is less likely to accept the single gamble when it is framed as an even chance to win 200 or lose 100 than when it is framed as a choice between w and an even chance at $w+200$ or $w-100$. Thus, the common aversion to fairly small favorable bets may be, in part at least, a framing effect.

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Figure Captions

Figure 1. A utility function for SC ($\theta = .93$)

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Dr. J. Lester
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495 Summer Street
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Washington, D. C. 20332

AFHRL/LRS TDC
Attn: Susan Ewing
Wright-Patterson AFB, OH 45433

Chief, Systems Engineering Branch
Human Engineering Division
USAF AMRL/HES
Wright-Patterson AFB, OH 45433

Dr. Earl Alluisi
Chief Scientist
AFHRL/CCN
Brooks Air Force Base, TX 78235

Foreign Addressees

Dr. Daniel Kahneman
University of British Columbia
Department of Psychology
Vancouver, BC V6T 1W5
Canada

Foreign Addressees

Dr. Kenneth Gardner
Applied Psychology Unit
Admiralty Marine Technology
Establishment
Teddington, Middlesex TW11 OLN
England

Director, Human Factors Wing
Defence & Civil Institute of
Environmental Medicine
Post Office Box 2000
Downsview, Ontario M3M 3B9
Canada

Dr. A. D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF England

Other Government Agencies

Defense Technical Information Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 copies)

Dr. Craig Fields
Director, System Sciences Office
Defense Advanced Research Projects
Agency
1400 Wilson Blvd.
Arlington, VA 22209

Dr. M. Montemerlo
Human Factors & Simulation
Technology, RTE-6
NASA HQS
Washington, D. C. 20546

Dr. J. Miller
Florida Institute of Oceanography
University of South Florida
St. Petersburg, FL 33701

Other Organizations

Dr. Robert R. Mackie
Human Factors Research Division
Canyon Research Group
5775 Dawson Avenue
Goleta, CA 93017

Dr. Amos Tversky
Department of Psychology
Stanford University
Stanford, CA 94305

Dr. H. McI. Parsons
Human Resources Research Office
300 N. Washington Street
Alexandria, VA 22314

Dr. Jesse Orlansky
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311

Professor Howard Raiffa
Graduate School of Business
Administration
Harvard University
Boston, MA 02163

Dr. T. B. Sheridan
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

Dr. Arthur I. Siegel
Applied Psychological Services, Inc.
404 East Lancaster Street
Wayne, PA 19087

Dr. Paul Slovic
Decision Research
1201 Oak Street
Eugene, OR 97401

Dr. Harry Snyder
Department of Industrial Engineering
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061

Other Organizations

Dr. Ralph Dusek
Administrative Officer
Scientific Affairs Office
American Psychological Association
1200 17th Street, N. W.
Washington, D. C. 20036

Dr. Robert T. Hennessy
NAS - National Research Council (COHF)
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dr. Amos Freedy
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. Robert C. Williges
Department of Industrial Engineering
and OR
Virginia Polytechnic Institute and
State University
130 Whittemore Hall
Blacksburg, VA 24061

Dr. Meredith P. Crawford
American Psychological Association
Office of Educational Affairs
1200 17th Street, N. W.
Washington, D. C. 20036

Dr. Deborah Boehm-Davis
General Electric Company
Information Systems Programs
1755 Jefferson Davis Highway
Arlington, VA 22202

Dr. Ward Edwards
Director, Social Science Research
Institute
University of Southern California
Los Angeles, CA 90007

Dr. Robert Fox
Department of Psychology
Vanderbilt University
Nashville, TN 37240

Other Organizations

Dr. Charles Gettys
Department of Psychology
University of Oklahoma
455 West Lindsey
Norman, OK 73069

Dr. Kenneth Hammond
Institute of Behavioral Science
University of Colorado
Boulder, CO 80309

Dr. James H. Howard, Jr.
Department of Psychology
Catholic University
Washington, D. C. 20064

Dr. William Howell
Department of Psychology
Rice University
Houston, TX 77001

Dr. Christopher Wickens
Department of Psychology
University of Illinois
Urbana, IL 61801

Mr. Edward M. Connelly
Performance Measurement
Associates, Inc.
410 Pine Street, S. E.
Suite 300
Vienna, VA 22180

Professor Michael Athans
Room 35-406
Massachusetts Institute of
Technology
Cambridge, MA 02139

Dr. Edward R. Jones
Chief, Human Factors Engineering
McDonnell-Douglas Astronautics Co.
St. Louis Division
Box 516
St. Louis, MO 63166

Other Organizations

Dr. Babur M. Pulat
Department of Industrial Engineering
North Carolina A&T State University
Greensboro, NC 27411

Dr. Lola Lopes
Information Sciences Division
Department of Psychology
University of Wisconsin
Madison, WI 53706

Dr. A. K. Bejczy
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91125

Dr. Stanley N. Roscoe
New Mexico State University
Box 5095
Las Cruces, NM 88003

Mr. Joseph G. Wohl
Alphatech, Inc.
3 New England Executive Park
Burlington, MA 01803

Dr. Marvin Cohen
Decision Science Consortium
Suite 721
7700 Leesburg Pike
Falls Church, VA 22043

Dr. Wayne Zachary
Analytics, Inc.
2500 Maryland Road
Willow Grove, PA 19090

Dr. William R. Uttal
Institute for Social Research
University of Michigan
Ann Arbor, MI 48109

Dr. William B. Rouse
School of Industrial and Systems
Engineering
Georgia Institute of Technology
Atlanta, GA 30332

Other Organizations

Dr. Richard Pew
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02238

Dr. Hillel Einhorn
Graduate School of Business
University of Chicago
1101 E. 58th Street
Chicago, IL 60637

Dr. Douglas Towne
University of Southern California
Behavioral Technology Laboratory
3716 S. Hope Street
Los Angeles, CA 90007

Dr. David J. Getty
Bolt Beranek & Newman, Inc.
50 Moulton street
Cambridge, MA 02238

Dr. John Payne
Graduate School of Business
Administration
Duke University
Durham, NC 27706

Dr. Baruch Fischhoff
Decision Research
1201 Oak Street
Eugene, OR 97401

Dr. Andrew P. Sage
School of Engineering and
Applied Science
University of Virginia
Charlottesville, VA 22901

Denise Benel
Essex Corporation
333 N. Fairfax Street
Alexandria, VA 22314

Psychological Documents (3 copies)
ATTN: Dr. J. G. Darley
N 565 Elliott Hall
University of Minnesota
Minneapolis, MN 55455

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